MANAGEMENT PROBLEMS AND CONSIDERATIONS IN UTILIZATION OF AUTOMATIC TEST EQUIPMENT

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ABSTRACT

Automatic test equipment performs a vital role in the operation and maintenance of many modern weapon systems. In some weapons systems, readiness appraisal and rapid fault location cannot be accomplished without the use of automatic testing. The techniques and equipment presently available are adequate to provide suitably programmed testing systems to meet a variety of requirements. Some of the problems that contractors and procurement officers must consider before final acceptance of proposed designs are presented and discussed. Basic requirements and desirable features are indicated. Some areas of research and possible future development of self-healing systems are described. Examples of operational systems are briefly described, and the application of each system indicated. A brief conservative philosophy for selection of a particular automatic test system is proposed.

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CHAPTER I

Introduction

The day Benjamin Franklin decided to go fly a kite is the day that the electronic revolution commenced. There have been many milestones along the way. The electric light bulb, transistors, vacuum tubes, printed circuits, and the development of automatic test equipment have contributed to the modern technological revolution in electronic systems. Test equipment has evolved from Franklin's house key through the test lamp, Wheatstone bridge, voltmeter, ampmeter, etc. up to the present automatic test or checkout equipment.

The years between the first functional electrical light and World War II are noteworthy for the commonly held belief that if a device or machine worked properly the last time it was used, it did not need to be tested before using again and should be left alone. The World War II era ushered in a short period of semi-automatic testing which was followed by several years of special purpose testing. As the number of parts per system soared and as production switched from quantity to quality in weapon systems, the growth of automatic test equipment proceeded at a rate only slightly less than meteoric. Old ideas changed just as radically and the belief now is it might work, but it cost several million dollars and thats too much to risk on a faulty relay--so test it!

The phenomenal growth of electronic automatic test equipments has been accompanied by an equal growth in adapting terms to describe the aspects of the industry. Just as each generation of teenagers invents a few new words or completely changes the meaning of old ones, so this new generation of scientific and engineering endeavor has its own peculiarities. "Redundant" has been generally accepted as meaning "extra" or "parallel" rather than Webster's familiar superfluous. "Dybology" is a name for the emerging science that is placed somewhere between biology and engineering. This word is partially derived using the prefix DYB meaning living-like but artificially created, and partially from the word "dybbuk" in Hebrew mythology meaning unassigned soul.

The proclivity of the government to refer to multiword organizations or systems by initials has been widely adopted by the electronics industry. Thus, automatic test equipment (ATE), Navy Radar Automatic Test Equipment (NARATE), and Digital Evaluation Equipment (DEE) are representative of the varied alphabetical designations to be encountered. The electronics industry may be said to have its own "dyblosemantic" proclivities.

The word "test" as used hereafter is defined as the process of making one or more measurements of a specific function to arrive at one or more diagnostic conclusions.

ATE itself may be defined as an electronic system designed to

analyze and isolate faults in another electronic system or device. This other system or device is commonly referred to in the industry as the unit-under-test or UUT. ATE for mechanical and pneumatic systems is also possible, but this subject is beyond the scope of this paper.

Normal test procedure uses a punched tape or card that has been prepared from a test routine prepared by a technician. The ATE, using this programmed information, transmits test signals to the UUT. The response to this stimulus is measured at various test points and the measured data compared with stored or computed information to determine whether the UUT meets operational requirements. Results are displayed in a "printer" or "reader" device. This device may indicate a simple GO or NO GO or it may furnish a detailed diagnoses complete with logistic data.

Automatic test equipment (ATE) performs a vital role in the operation and maintenance of many modern weapon systems. It is used to check out missiles during prelaunch--and in operation. Aircraft systems depend heavily on automatic equipment for periodic and normal pre-flight inspection. The Navy is using ATE to monitor radar performances. The role of such test equipment is being extended into remote checks of vital equipment installed in radioactive areas or other environments injurious to man. Expansion of ATE into other vital and semi-vital areas is a near certainty.

Automatic test systems are costly. The present system used to checkout the Atlas missile costs approximately the same as the missile itself. Other test systems designed specifically for an item of prime equipment (PE) also have costs comparable to the PE itself. The cost and effectiveness of any complete system depends a great deal on the effectiveness of the required test system which includes not only test equipment, but the men and materials necessary to operate and maintain the equipment. However, once ATE is procured for one prime system, its cost may be amortized over all other prime systems with which it is integrated--provided integration is possible. Integration of ATE to other systems reacts to reduce costs further by reducing manpower needs and possibly technician training. The financial value of increased reliability and operational time of prime equipments realized through use of ATE, although impossible to accurately ascertain, is extremely significant.

This paper is intended to present some of the problems and considerations that should be recognized before an automatic test system is procured. All large and many small firms in the electronic industry are producing or developing ATE in one form or another. Like automobiles, some are bigger than others. Some are also better than others, but an effective evaluation of which is best depends on what it is expected to do. Some constraints are obvious and will not be explored. For example, an ATE that takes a half dozen trucks to haul

it around is obviously too large for a destroyer although it may be acceptable for an Air Force missile system.

The chapter on human factors touches lightly on an area considered vital for effective and harmonious maintenance of a complex electronics system. The areas of systems analysis and function allocation have been the subject of an enormous amount of research, and the reader is invited to references (12), (14), and (16) for an analysis in depth. Reference (11) is a publication particularly important to military procurement officers when considering any electronics system.

Self-testing features are a relatively new but extremely important aspect of any ATE system. The need for an ability to "test the tester" is obvious, but has actually received very little attention in the past. Feedback to producers from field operators have indicated that considerable time has frequently been lost looking for faults in prime equipment when the indicated malfunction was really in the test equipment. Also, time spent maintaining test equipment was all out of proportion to that spent on prime equipment. Chapter 3 presents some of the problems and considerations of self-testing features.

Beyond the present generation of ATE, scientists and engineers foresee the probable development of "self-healing" test systems. This concept is essentially one of instilling some of the abilities of the human brain into test computations. Some of the studies and research

into "self-healing" systems are presented in Chapter 4.

The chapter on contemporary systems is included to briefly illustrate a comparison (and disparity) of present ATE characteristics. This information is included as a possible aid in assisting military procurement officers to obtain "a dollar's value for a dollar spent."

CHAPTER 2

Human Factors in Utilization of Automatic Test Equipment

Early studies involving man-machine tradeoffs in using ATE indicated that some of the basic reasons for using such a system were not being realized. Automatic equipment by definition requires less operator participation and judgement than a manual system. The shortage of personnel with adequate skills to perform varied and multitudinous test procedures presented a severe problem in operating and maintaining complex equipment. The appearance of ATE was widely hailed as the answer to the personnel problem. Unfortunately, far from decreasing the numbers and skills required, early ATE systems actually required more personnel although less test time is generally required. To make matters even worse, the skills required to adequately use ATE were discovered to be of a somewhat higher order than those used in manual testing. Such unexpected results have necessitated a complete reassessment of all factors involved in ATE.

Research and development have produced ATE systems with capabilities that existed only in dreams twenty years ago. All too often these capabilities have been exaggerated and the limitations of the system understated--if mentioned at all. Consequently, when an unstated limitation was found in an operational situation, the operator lost a little confidence in the system. After several "little losses"

the operator retained little or no confidence and tended to ignore the very real capabilities which did exist. The capabilities and limitations of ATE vary with the particular system and are constantly changing with experience and new developments. Operators must know both the capabilities and limitations of ATE to efficiently use the system.

Man on the other hand is the product of centuries of research and devlopment by nature. As a functioning mechanism, he is a constant and is supplied in essentially one configuration. Training and education are tehcniques of effecting changes in man, but such changes are rarely radical in nature. The capabilities and limitations of man must be recognized before an effective ATE can be designed. A system that cannot or will not be used for its intended purpose is a waste of time, money, and effort.

Capabilities and Limitations of ATE Operators

One of man's primary characteristics is his variability. Inter-individual differences are easily observed and decisions based on these differences should be relatively simple. For instance, a 97 pound weakling cannot be expected to man-handle the 120 pound building blocks that exist in some ATE systems. Intra-individual differences are not so easily recognized. The boundary conditions and limits of human behavior can be measured with reasonable accuracy, but the variations in behavior between these limits are difficult to measure.

Even a reasonably definitive measure of an individual's sensitivity in one setting is no reason to assume that he will perform the same in a different setting. Machines cannot be developed to conform with each individual, but consideration should be given to the broad limits of human behavior.

Human operators have unknown levels of potentialities. Most human capabilities are not comparable to machine capabilities, but are complementary to them. Man's greatest advantages lie in perception, motor skills, intelligence, and flexibility. Effective designs recognize this superiority.

Humans perceive patterns and not just isolated bits. These patterns are not restricted to one sense but may be perceived by two or more at the same time. An operator can see a change in rate or degree of vibration, hear strange sounds, and smell unusual odors all at once. He perceives that something is wrong and can stop the machine before it breaks down or destroys itself. Man can see patterns on an oscilloscope and detect small variations that precede eventual breakdown. This ability to perceive a pattern of events occurring over time and thereby anticipate future events is behind much of his ability to learn.

The human body, within limitations, is the one most efficient instrument for motor activity. Several complex machines would be required to grasp and move the large variety of objects that are

easily manipulated with the hands. The eyes and hands working together are unmatched for fine adjustment and calibration of instruments and for application of hand tools used in repair or replacement of parts. Man's sense of balance is as yet unmatched for stacking objects. Man's muscular flexibility and mobility also enable him to move about freely simultaneously in a variety of ways that cannot be matched by any known machine.

Man's intelligence gives him certain basic abilities that must be used to successfully complement machine operations. The ability to learn from experience and thereby improve performance is necessary to achieve effectiveness in assigned tasks. The ability to improvise often enables operators to use machines in field situations much more efficiently than anticipated. Man thus complements machines by compensating for two general weaknesses found in ATE:

1. Failure to design a system to adequately do tasks that in operations are found necessary or desirable.

2. Inability of the system to do well (or do at all) that which it was designed to do.

Operators learn shortcuts, new techniques, and suggest design improvements and procedures that are impossible to predict without experience. This flexibility is man's greatest advantage in a man-machine system.

Man can "degrade gracefully," while machines can function only

in their prescribed manner. Machines that are overloaded or subjected to an unusual environment become ineffective or even destructive. Men compensate and modify their performance so that although they fail to do a good job, they continue to function in some limited fashion. In adversity a machine will generally turn out a useless product or none at all. Men usually turn out a poor but at least an acceptable product under adversity. Man is also self-correcting and can usually detect faulty output and thus improve or correct his performance.

Humans have several real functional limitations that can only be overcome by machines. Compared to machines man is physically weak and relatively slow. He is easily and rapidly satiated with routine tasks which are dull and boring, and usually reacts by going to sleep or by "day dreaming." System designers should be careful to take man's physical limitations into account and avoid situations that require a man to operate beyond his physical capabilities.

Humans make errors. This is a frequent argument to recommending man's replacement by a machine in certain situations. However, many malfunctions due to human error result from human engineering that requires an operator to do a job under conditions poorly designed for him. Man's flexibility in compensating for poor conditions result in far less attention being paid to his environment than is required in machine design. The cost of such inattention is unnecessary human errors. Such errors could exact a terrible price in a military emergency.

Human operators are impatient. In test situations involving fixed sequences, the temptation to improvise or skip tests is frequently overpowering. Errors often occur from such experimentation, but they are the price of using an intelligent being. This experimentation does add to man's store of knowledge and often eliminates undesirable features in later developments. An ATE can be fitted with safety interlocks to prevent catastrophic errors.

Men must be motivated. ATE was loudly acclaimed as a system that could be operated by a trained ape. Consequently, some operators have been prone to shed all responsibility for the success of the system and follow instructions only to the letter and not the spirit. Malfunctions have naturally occurred with surprising frequency. Men also have minds of their own and their interests may be independent of or in opposition to the goals of the entire system. Motivating the operator is the price of having an all-purpose calculator that can take over and do a job when the machine proves recalcitrant or deficient.

Capabilities and Limitations of Present ATE

There are several kinds of ATE which do not share common capabilities or limitations. All test and checkout missions are not the same so that applications in one area will not work in another. Features required for diagnostic testing are generally unnecessary and perhaps detrimental to effective confidence testing. Some apparent

limitations of ATE may actually result from the design of the prime equipment (PE) with which it is associated. Other limitations may be the result of an inappropriate environment. The lack of adequate air conditioning and power supplies may result in inefficient operations of the system. It is also possible that some capabilities attributed to ATE are actually the result of an operator's ability to keep the system working in spite of certain shortcomings. However, there are basic capabilities and limitations which are common to most ATE systems.

ATE is fast. Because of its high speed, automatic equipment can do quick operational tests. It can do more testing in far less time than man and is particularly valuable in checking systems that are prohibitive in time to test manually. Its high speed in testing such items as missiles result in fewer test-induced malfunctions.

ATE has good test control ability. It can readily control complex closed-loop and dynamic tests. It can conduct simultaneous tests and, if properly programmed, can eliminate some human error.

Because ATE can use digital computer techniques, it can utilize test patterns designed by highly skilled technicians who are unavailable at operational sites. It can perform diagnostic functions employing logical analysis, functional analysis, or simulation. It can also correlate data and produce a logical pattern that is beyond a single operator's capability.

Automated equipment, if so designed, can be used in environments dangerous to men. It can be used to remotely monitor equipment that is in a radioactive environment. In conditions of extreme cold where man is unable to remain for the time necessary to adequately check equipment, ATE may be the only possible way to conduct tests. The economic loss of a machine does not have the emotional significance that death or injury to a man brings forth.

The most serious limitations of ATE are those inherent in its design. It does only what it is told to do, and, unlike man, it cannot improvise nor plan and execute new tests that may be indicated. Programming may be inadequate since some tests needs are not readily anticipated during the formative stages of a system. It is more complex than redundant manual equipment and is, therefore, sometimes less reliable. Self-test features may be included to offset some of the reliability problems. ATE that does not contain a digital computer may be inflexible with respect to acceptance and rejection limits. A "go-no go" configuration is fixed and does not have compensation features for complementing drifts. If test readings are oscillating between limits, this fault will go undetected whereas a manual meter could quickly spot the fault.

ATE is more complicated, takes much longer to design, and is more expensive than a manual system. Particularly expensive to automate are non-electrical stimuli and wave-form analysis. A requirement

that the prime equipment be operational during test operations adds significantly to the cost of the system. Such requirements are almost sure to exist in developing a system for military usage; e.g. radar search equipment.

ATE sometimes does not find an existing fault or properly indicate a prime equipment's true condition due to insufficient or inadequate test point access. Inadequate test points are usually the result of poor PE test design, but are sometimes due to having different contractors responsible for the PE and its ATE. It is not uncommon for causing modes of failure to be unanticipated and, therefore, the proper tests are not programmed. ATE must also be designed to find faults that would show up only in the extreme environment of operations. It is difficult if not impossible to test for faults in pressure systems that are developed to operate in a vacuum such as outer space.

ATE is relatively inflexible. Changes that occur in PE often make it extremely expensive to modify accommodating changes in the ATE. Test programs are difficult to update, especially in field operations. Further difficulties may arise when PE changes are delayed so that test equipment may keep up with the changes. This "cart before the horse" concept occurs when serious consideration is given to designing PE or changes to PE to conform with existing ATE. However, cost effectiveness studies may well reveal that relative

flexibilities make this approach much cheaper.

ATE design often impedes the teamwork necessary between man and machine. Because of limitations such as unreliability, inflexible test limits, unanticipated faults, incomplete testing, etc., the operator is often required to augment the ATE. This is particularly so when the ATE cannot locate or diagnose in fine detail a fault that obviously exists. Without adequate quantitative information, the operator must fall back on time consuming manual methods. Manual overrides, backups, self-test and retest configurations must be provided to assist in diagnostic testing. An immediate self-test capability and the ability to do an immediate retest of questionable sections will in some cases materially reduce maintenance time and effort.

One of the most common limitations of ATE is lack of general acceptance by the user. Experience in using the system will usually overcome such objections, but in some cases experience will merely strengthen the objection. If the operator considers the equipment as basically inadequate for its intended purpose, he will see each malfunction as confirmation of his judgment.

Occasionally the test time for ATE actually exceeds the time required to perform a manual check. This is particularly true if difficult and lengthy hookups are caused by a multiplicity of test cables. Experience may have shown that a certain type of fault has

a high probability of being in one certain area. Without test sequence flexibility, long annoying delays may occur while the test sequence moves to the series that the operator feels to be appropriate. This could result in operator rejection of ATE. Such rejection is fairly common among highly skilled technicians and may be partially attributed to the propensity of such technicians towards manual testing.

ATE and ATE Operator's Capabilities and Limitations for Each Test Action.

Sidney I. Firstman and Nehemiah Jordan of the Rand Corporation[1] have, through study of numerous testing activities, concluded that all tests and test sequences are composed of some of the following series of actions:

1. Sequence: Order and Rank tests.
2. Prepare: Set up, Connect, Adjust, Connect, and Switch Test Equipment.
3. Run Test Step: Perform Actual Test Operations.
4. Measure Results: Convert, Measure, and Physically Compare Test Results.
5. Assess: Ascertain Meaning of Test Step or Test Sequence Results.
6. Record Results of Test.
7. Decide: Determine Next Action.

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[1]Sidney I. Firstman and Nehemiah Jordan, "Operational and Human Factors in Planning Automated Man Machine Checkout Systems," Rand Corporation Memorandum RM-2835-PR, April 1962, pp. 22-27.

Not all actions are done for each test, nor do they all follow the same sequence. However, all test actions are considered, although most of them require certain manipulations for repair, alignment, calibration, and adjustment. Most automatic or semi-automatic operations are performed by machine while manual operations by definition are performed by humans.

Initial test sequences and operations are difficult and expensive to develop and program. Modes of failure are not all anticipated and tests as programmed do not always locate an existing fault. ATE retains and follows precisely preplanned sequences while man finds it so difficult to follow a fixed pattern that he generally uses a check-off list. Follow-up sequences may be so inflexible that operators are unable to go to specific tests or sequences, nor are they allowed to skip tests or retest specific areas. ATE, if programmed to do so, can sometimes determine required characteristics of follow-up tests from results of preceding tests, but it cannot improvise or create new tests should a need arise. Man can improvise and often improve upon a prescribed sequence.

Preparation time is a function of the number of test cables and similiarity of test equipment. Man's perceptive and muscular skills are necessary to sort out and hook up test cables. Standardized equipment for identical weapon systems will enable an efficient transfer of operator techniques. Clearly labeled cables and non - interchangeability of plugs will help to minimize man's proclivity

for error in the hookup process. Permanent hookups can be initially checked out for errors and thus eliminate any subsequent mistakes in manipulation of cabling. They would also reduce significantly preparation time.

ATE uses electromechanical timing and switching to start and stop test operations. It usually has the capability to effectively monitor both the PE and test equipment during the checkout sequence. Men, however, are generally poor monitors of a constant unchanging state, but are quite sensitive to unexpected changes or deviations. Working together, man and machine can efficiently conduct checkout operations and complement each other in monitoring the process.

ATE excells in measuring and comparing test results. Some systems have relatively crude comparators and may produce inconsistent comparisons. However, men tend to make mistakes in routine comparisons and even poorly designed ATE is usually more consistent.

With experience, human operators can evaluate test results on a more sophisticated and complex level than ATE. They can relate other test results and frequently anticipate malfunctions. ATE is capable of evaluating and comparing accumulated data computations by either digital or analog computers and is thus much faster and more accurate than men.

ATE can be designed to record data in almost any form, but it is difficult, time consuming, and expensive to change a recording

program. On the other hand, man can change a recording program quite easily. Men are slow and tend to make errors and may even falsify records deemed detrimental.

Properly preprogrammed ATE can indicate preferred subsequent actions. a preprogrammed decision is equivalent to standard operating procedures, and SOP by its definition is to be followed unless circumstances clearly indicate otherwise. These "other circumstances" are by nature unspecifiable and a human operator is necessary to supervise the decision in the light of existing circumstances.

Summary

The successful design of ATE is an art that requires an extensive background or experience in electronics as well as talent and perception. To achieve system harmony the test equipment must be designed with man-machine tradeoffs in mind. Some reasonable idea of the mission of the prime equipment with which it is to be associated should also be considered. The physical and operational environment in which the equipment is to operate should be considered in detail. Knowledge in depth of the capabilities and limitations of man and machine are necessary if a design is to be efficient and effective.

Serious consideration must be given to the mission of the ATE; whether confidence or diagnostic,ATE is more effective as a confidence tester than as a diagnostic tester. Confidence testing is conceptually simpler, and it is always easier to define procedures that ascertain

whether a system is mission ready than to program routines for finding causes of malfunctions. A confidence test is designed to be somewhat independent of design details in system modules, while diagnostic tests are critically dependent on design details. Confidence tests may not change with module changes but diagnostic tests will surely require modification.

Another significant consideration is the availability of technically trained personnel. A confidence test, for instance, gives a final answer as to mission readiness. If the answer is "no-go", then some action is indicated, and if there are no trained maintenance personnel outside of the production laboratory, a diagnostic test is a waste of resources.

Finally, designers must consider that ATE is but one item in an overall system. The prime equipment is the reason, man is the user, and other men and systems are required to furnish the wherewithal to keep the system operational. Automation of test and checkout activities transcends mere engineering--it requires a system structure that is both physically and organizationally harmonious.

CHAPTER 3

Self-Testing of Automatic Test Equipment

The complexity and diversity of an integrated automatic test system requires that some form of self-testing be included to avoid excessive requirements for maintenance. Self-testing must be comprehensive, but it must also be fundamentally simple in operation. If military personnel are to operate and maintain complex weapon systems in areas far remote from design and production engineers, then some system to ensure operational reliability must be pursued. Self-test provisions for installed automatic test equipment is one such system.

Effectiveness of a test system may be measured as a ratio of operating time to downtime. This ratio may be increased by increasing the mean time between failures (MTBF). It may also be increased by decreasing the mean time to repair (MTTR) the system after a fault has occurred. Self-test philosophy is pointed toward reducing downtime by providing a rapid effective means of fault detection and by isolating the fault to the lowest replaceable module. Maintainability goals of most ATE systems are on the order of thirty minutes mean downtime per failure. The MTBF is a function of many factors, but should certainly be reduced through effective monitoring of subsystem operating limits.

Types of Self-Testing

There are two basic types of self-test; programmed and automatic light monitoring. Each is capable of accomplishing many of the functions accomplished by the other.

Programmed self-tests require the use of taped programs. Such programs are written in computer language on magnetic or paper tape and are derived from flow charts of the ATE. Design engineers play a most important role in acquiring an effective tape since poorly constructed or inaccurate charts will result in "GIGO" (Garbage in, Garbage out). The programmer cannot schedule a test point that does not show on the working chart. Five different tapes are usually prepared for acceptance, confidence, survey, safety, and diagnostic testing.

An acceptance test is a complete self-test program to prove that all unit subsystems are operable and within normal operating limits. This test is relatively long. It is used primarily for contract acceptance, overhaul acceptance, and system appraisal after long periods of inactivity. A ship might use this test in preparing to get underway after an extended leave and upkeep period to ascertain that the test equipment is operational.

A confidence test is a program which provides operator confidence in the operability of the entire system. This program should be run at least daily during normal operations. It could be run at the

beginning of a watch to provide on-coming personnel with a high degree of confidence in their assigned equipment.

A survey test is a program that checks all system elements to be used on a unit-under-test (UUT) test. It determines the status of all subsystem elements such as measuring equipment, power supplies, and microwave stimuli. It is essentially a confidence test to reassure maintenance personnel that their "tools" are in operational readiness. This test should always precede a UUT test.

A safety test is a short routine that is run during a UUT test. Its purpose is to ensure that the application of a stimulus will not injure personnel or equipment by application of incorrect stimulus values to specific units. It has the added advantage of reassuring personnel that the test procedure is safe.

A diagnostic self-test is a program written with the assumption that a fault exists somewhere in the system. By comparing existing stimuli from each element with predetermined standards, the test should indicate test program at that particular point. Diagnostic tapes are a significant improvement over the initial GO-NO GO tests for such systems.

The Navy Radar Automatic Test Equipment (NARATE) utilizes programmed tapes for self-testing. This tape diagnoses faults in the ATE in 2.5 minutes. Since NARATE is modularized, the removal and replacement of faulty assemblies is accomplished in a mean time of

7.5 minutes. This provides a MTTR of 10 minutes and an availability of over 99.9 percent based on a MTBF of only 200 hours. The mission availabilities of the radars monitored by NARATE are significantly enhanced by the high order of test equipment availability.

The automatic monitoring system is an integrated network of test points continuously monitored for failure. In most cases this failure consists of an absence of signal which turns on a red display light. Each chassis or "black box" contains its own malfunction display and malfunction output line. These lines generally feed into a central rack configuration with lamps oriented according to chassis location. A green lamp indicates normal operation and a red would indicate a malfunction. Both lamps off would indicate a power failure. Subsystems which, if faulty, would pose a hazard to personnel or equipment or would affect a test in progress may be tied into an audible alarm. Sufficient test points are essential for an adequate automatic monitoring self-test.

The philosophy behind automatic monitoring appears to be that a system designed to test automatically a functional system should be able to test itself automatically. However, the complexity required of most ATE precludes self-testing down to the lowest replaceable unit by automatic monitoring. Isolation of faults to a specific block in a particularly complex system through continuous monitoring is by itself a significant time saving factor. A programmed tape could then

be utilized to further isolate the fault down to the specific unit or element.

Critique of Self-Test Methods

Although both methods of self-testing are capable of accomplishing many similar functions, each has its own peculiar advantages and disadvantages. Programmed self-test has the unique advantage of providing a complete system confidence check. It is the only completely satisfactory means of dynamic testing the operability of complex logic arrays. Once programmed tapes have been proven, then very little maintenance cost is associated with self-testing. Automatic self-testing is unique in presenting a continuous check on the ATE. It is particularly valuable in fault isolation of the power system. It can also be used to monitor certain sections of the ATE when it is inoperative.

Disadvantages associated with the programmed method are increased programming time and cost, self-test limited to areas under program control, and the necessity of obtaining a complete set of tapes. Automatic monitoring increases the cost and complexity of the system. Poor design in the self-test portion of a system also presents problems in maintaining the self-test system. Using a dual self-test system would eliminate most of the disadvantages but would increase cost and complexity.

A dual self-test capability is particularly important in solving the problem of "checking the checker." There are three conditions

possible in a self-test system:

1. No fault present and none indicated.

2. No fault present but a fault indicated.

3. A fault present but none indicated.

The first condition is "true happiness" for an ATE and requires no further consideration. The other two conditions could be serious and deserve some consideration.

The incidence of fault indication with no fault present can be minimized by redundancy in the indicator system. In automatic light monitoring the lamp system includes a lamp on the chassis at the fault location with another at the central rack. An audible alarm may also be employed so that multiple redundancy will practically ensure that a fault is actually present when it is indicated.

The condition of having a fault but no indication is a critical problem. This cannot always be prevented since the faults monitored are largely catastrophic in nature in the light monitor system. An extremely complex system is required to detect and indicate such malfunctions as component drift. In order to prevent excessive dependence on a light monitoring system a programmed check must be run periodically to test both the system and the automatic monitoring system. Manual procedures can also be employed to check the self-test system.

The maintainability of any electronic system is directly related to the care with which test points are selected during the design phase

of the program. Test points must be appropriate and sufficient in number to allow automatic monitoring of functional units without removing subassemblies from the rack. Test points are brought to a single connector on the chassis with the entire block or subassembly being monitored at once. Generally all inputs, outputs, and selected intermediate points of a functional unit must be brought out for a satisfactory isolation of faults.

Test points for programmed self-testing should be sufficient in number to allow fault diagnosis of the lowest replaceable module. This means that test points should usually be provided on both the input and output side of each replaceable module. Standard voltages and frequencies are used as references for the system. These standards must be checked at periodic intervals to ensure their accuracy to specifications. Poorly selected or insufficient test points will result in increased maintenance time of the ATE.

Summary

The necessity for ATE is based on a prime system which by virtue of its complexity, mission availability, and reliability requires a low mean time to repair. Factors which dictate the need for ATE are the same factors which dictate the necessity for an ATE self-test configuration. A MTTR of ten to thirty minutes for an ATE is impossible without a self-test system![1] In event of simultaneous faults in the

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[1]NAVSHIPS 94324, Maintainability Design Criteria Handbook, indicates that for an MTTR of 0.2 to 0.5 hours for PE, fully automatic test equipment for fault location must be used.

prime equipment (PE) and ATE, the additional downtime of the PE could reasonably result in mission failure.

Self-test of ATE results in increased weapon reliability, increased confidence in the PE system, and decreased necessity for specialized technician training. Although the complexity required for self-test features increases the cost of the system, long range savings in technical training may level out the cost effectiveness considerations. Increased personnel time in operational billets derived from decreased time in training may be significant. The value of command confidence in the entire system may be equally significant. Regardless of the criteria used in evaluating the costs of self-testing systems, the costs of not having it are potentially much greater than the expense of procurement.

CHAPTER 4

Increased Reliability Through Self-Healing

Extensive and intensive efforts are being made in research and development to produce parts for products strong enough to last the life of those products. The ideal product would then be one that lasted for a predetermined period with all parts failing at the same time. This high order-of-magnitude improvement in product reliability is technically possible. However, increasing outlays of resources are presently achieving decreasing gains in long enduring or failure free products. A possible breakthrough in the search for predetermined or semi-infinite product reliability is the dawning realization that self-healing products are perhaps possible.

A self-healing product is one that has the capacity to continue its functional output in the event of a break-down or malfunction of its elemental components. Some degree of self-healing has been present in machines almost from their inception. Putting oatmeal in low pressure steam boilers to plug up minor leaks that develop is a procedure almost as old as the boiler itself. Any machine containing a device designed to stop it to prevent further damage when an important part fails may be included in the self-healing category. The shear pin that prevents an outboard motor propellor from completely destroying itself is a common example. More sophisticated examples include self-healing gas tanks and tires. These employ a soft mastic

material on the inner surface which is forced into punctures by internal pressure. Future progress in self-healing products will be but an extension of these or similar efforts.

Degrees of self-healing.

The more complicated the process of self-healing, the more complicated must be the system which accomplished the self-healing. Therefore, seven degrees have been selected to correspond with system complexity:[1]

1. Fixed redundant.
2. Time elapsed redundant.
3. Sensing and switching redundant.
4. Random redundant.
5. Self-maintaining.
6. Self-sustaining.
7. Self-organizing.

The first four are grouped in a "closed" category as those which are not dependent on external sources for spare parts. Required spares may be periodically inserted or replenished by humans, but this process is not a normal part of the system's daily function. The last three are grouped as an "open" category in which spare parts are continuously

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[1] Richard R. Landers, "Achieving Higher Reliability Through Self-Repair," IEEE Transaction on Aerospace, Vol. AS-1, No. 2, August 1963, pp. 735-737.

supplied or obtained from an external source. This replenishment is considered a normal function of daily operations.

The fixed redundant type is the simplest and most common. An example is the dual filament bulbs used in navigational lights. When one filament burns out it is only necessary to turn the control switch to an alternate "on" position to restore illumination. The advantages which accrue from a safety or legal viewpoint should be obvious. A slightly more sophisticated example is a power supply with dual output tubes wired in place. The power supply continues to operate within specifications when either tube fails. Dual ignition systems in aircraft are another common example.

Time-elapsed redundant types are those in which subassemblies or modules subject to predictable wear are replaced automatically at fixed intervals. Replacement is geared to a constant wear rate, and new parts may be inserted as well as automatically switched into action. Ignoring the wear of non-replaceable parts, the life of this type system is a direct function of the number of initial spares and the time interval between replacements.

Sensing and switching redundant type systems have components which detect failures and switch to previously wired-in standbys or spares. Von Neumann's multiplexing scheme which will be explained later in this chapter is an example of the type. Long-distance telephone circuitry also uses this type of redundance on the amplifier assembly level. This

type of self-healing system is essentially the present limit of operational models.

Random redundant systems have self-contained spares that are not predestined for a specific location. These parts will contain sensing devices and have the added capability of self-removal when worn out. This type represents the most complex of the "closed" type systems.

Self-maintaining systems are the first or lowest degree of the "open" type systems. These type systems contain a supply of spare parts which can be replenished from an external source. They will also have the ability to test spares in storage and eliminate the faulty ones.

The self-sustaining system has the ability to obtain its own material and energy requirements. They are capable of reproducing themselves, but only in their own or similar configurations. Man is the highest order of self-sustaining systems.

Self-organizing systems are envisioned as ones which can grow and expand in both size and operational functions. They would not be limited to reproduction in their own configuration, but would have the ability to change as necessary to perform varied functions. They are thought of as a community of single machines or systems which act as a group rather than as independent entities.

Reliability Aspects

Each of the seven types or degrees of self-healing systems have specific capabilities and limitations that are inherent in their

configuration. The life span or reliability of each system is expected to be in conformance with the degree of complexity of the system. However, the reliability of the four highest order systems is postulated from what is expected rather than what has already occurred, as in the lower three.

Fixed redundant systems generally have a standby element carry the load in event of failure to the first element. Or both elements may be equally loaded to extend the useful life of the system. However, if the failure hazard to the system is common to all operating elements, then the standby principle can be clearly considered as more reliable. The Mercury capsule systems currently use as many as two complete backups or standbys.

Prediction of system reliability for time-elapsed redundant systems is largely dependent on two factors. There should be little or no unpredictable deterioration of spares, and the hazard to replaceable parts should be limited to wear. Exponential law or Monte Carlo simulation should be employed to predict reliability in the face of hazards which can affect all elements of the system.

Sensing and switching redundant systems have the ability to monitor a critical factor such as output and automatically replace a defective element. Von Neumann[2] has introduced a majority concept

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[2] J. Von Neumann, "Probabilistic Logics and the Syntheses of Reliable Organisms from Unreliable Components," Annals of Mathematics Studies, (Princeton, New Jersey: Princeton University Press, 1956), No. 34, pp. 43-98.

which he calls multiplexing that falls generally within this type of system.

The general idea of the majority concept seems to be that three units, each of which in proper operation is capable of giving an adequate solution to a problem, would be connected in parallel, and the output of the entire system would be that upon which two of the units agree. This output is to be selected by a two-out-of-three majority "gate." The majority gate would "count the vote" and indicate the output "elected" as well as any circuits that fail or are in the "minority." The minority could then be checked and repaired. The great limitation of this concept is that the majority organ itself can cause a system failure.

By multiplexing the system, Von Neumann's idea seems to be that a system should have many identical units operating simultaneously on the same inputs and have an equal number of restoring organs. The output from each restoring unit would be fed into only one of the units in the following stage. With several majority gates in the system, each of these could correct the outputs from non-concurring organs and present identical values on the output side of the gate. Should a majority gate fail, then the input to only the next or following functional organ would be incorrect and its output would be corrected by the majority gates following that stage. Complexity of the system arises from the necessity to use a set of majority gates at each output.

Another problem arises at the end of the system when all inputs have been operated on and some sort of usable output is required. A failure here would negate the whole system. Also, if only one indicator is used, its failure would negate the entire system and additional majority gates would be superflous. However, an error at the end of a system such as this would have a much lower probability than a straight linear system, and could usually be detected by conventional observation.

The most obvious advantage derived from such a system is that repairs to sections may be accomplished without interrupting the normal output. Such a system is becoming increasingly necessary in air-traffic control computations and, to a slightly lesser degree, in vehicular traffic control. Space travel may also require systems which must maintain a continuous usable output even though interim repairs are being conducted. A multiplexed system can tolerate many failures at the same time, but if such failures are allowed to accumulate, then the entire system will fail. Prompt and efficient detection of failures could be indicated by the addition of a simple circuit. This circuit would measure the degree of correlation between outputs that are supposed to be similar and turn on an indicator when the error rate exceeds a preset value. Repairs to a faulty circuit or element are not essential to the normal operation of the system and need not be made redundant. However, periodic maintenance should be performed at

frequent intervals.

Random redundant type systems have better reliability since they do not require the fixed wiring and switching mechanisms of the simpler self-healing types. Random redundancy requires a high degree of non-differentiation or standardization of spares. This enables the system's life to extend until the entire reservoir of spares is consumed and assures a more efficient utilization of constituent elements. As an example, present electronic systems in the Armed Forces consume approximately three percent of their parts. The remaining elements are usually in good working order when the system is discontinued since the wired in spares (fixed redundancy) are currently designed so that few parts fail due to wear alone. Even though parts in the "ready reservoir" deteriorate at a rate equal to active elements, the overall system life in random redundancy is on the order of two to three times the mean life of the spare elements. This reliability factor is based on the assumption that the spares have a normal failure distribution.

In the "open" types of self-healing systems the system life is not limited to the fixed reservoir of spare elements. Replenishment of spares and removal of waste (worn-out or failed parts) is accomplished continually or at fixed intervals. The primary consideration of self-maintaining systems is that replenishment occurs at least at the same rate as parts are consumed. The reservoir in such a system must, however, be large enough to accommodate periods of high usage. The

potential life of self-maintaining systems is considerably longer than that of the "closed" systems, but it is definitely finite in time. Not all parts are replaceable, such as intricate wiring, and there will always be an accumulation of waste that cannot be completely removed. While minor damage is self-healing, the cumulative nature of residual effects will ultimately wear out the overall system.

Self-sustaining systems have the ability to seek out and process materials as required for continued functioning. If the term self-healing is taken literally, then it is possible that a self-sustaining system will remain functional as long as the necessary resources are available. Such a system will have the capacity to replace complete units or assemblies rather than single elements as in the simpler types. By stretching the accepted definition of machines the concept of "bioelectric power sources" or "bug batteries" may be considered a self-sustaining type.

Experimental power sources operating by bacterial action have been developed.[3] Bacteriological fuel cells operate on the fact that rot-causing bacteria strip hydrogen from the hydrocarbon compounds that they decay. Then, via the hydrogen-transport mechanism, they combine hydrogen and oxygen, forming water and energy to power their own metabolism. Excess energy shows up as heat. Using an external

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[3]Sam Barnes, "Bioelectric Power Sources," Machine Design, December 5, 1063, pp. 120-124.

circuit to partially harness this energy, Dr. F. Sisler and Dr. R. I. Sarbacher of the National Scientific Corporation, have developed a model bacteria cell. Based on a sea water medium, their cell puts out two volts for months by adding small amounts of sugar for fuel or food. A crucial part of the cell is a membrane between the electrodes that passes OH ions while preventing passage of 0_z ions. The developers have speculated about placing electrodes and membranes in the Black Sea and lighting up half of Europe and Asia![4]

When extended space voyages are contemplated, the self-sustaining systems deserve more than passing consideration. Bacterial cells could be fueled using human waste, thus solving one perplexing problem. The reproduction process of living organisms would solve the spare parts problem and ensure a long lived power source. (A typical mercury cell battery lasts 30 hours.) Another possible advantage is less weight and better compactness. Biological membranes discharge on the order of 0.1 watts per gram while the mercury battery (weight: 5.85 oz.) yields an equivalent of 0.003 watts per gram. However, the art is still in basic research and until hoped-for breakthroughs occur, applied research will be delayed. It may some day be possible for the mountain folk to enjoy the wonders of an electrical home using power generated by the septic tank.

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[4] Ibid.

Self-organizing systems are somewhat more than self-sustaining. They are envisioned as having an infinite reliability. The only constraint on their "perpetual motion" classification is that which would be imposed by some natural or deliberate catastrophe. The critical question concerning such a system is "do we really want it?" The carefree bliss that would accompany such a dybosphere (machine world) might be too much of a nightmare. The meager chemical constituents of the human body might eventually be just what such a system of machines desired and the survival of homo sapiens would depend on the destruction of his efforts. Indeed, going just a step further and assuming that such a system would be subject to the same organizing forces that affect humans, one all-inclusive single machine must be seriously considered. Scoffers are directed to the "homeostat" built by Ross Ashby.[5] This machine adapts itself to changes in external environment and is "goal seeking." It is functionally self-healing since some of its wiring can be removed and others connected at random with the machine eventually readjusting itself to proper functioning. The implications are interesting to say the least.

<u>Summary</u>

Self-healing systems are a significant turning point in man-machine technology. The extension of current practices are not expected to result in the required technological breakthroughs that

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[5] Ross Ashby, <u>Design for a Brain</u>, (second edition; New York: John Wiley and Sons, Inc., 1960).

will increase reliability or endurance on the order of magnitude that is necessary for anticipated goals such as space exploration. Extensive development of "closed" type self-healing systems can be reasonably expected. "Open" type systems may be much slower making their appearance on the operational scene, but research efforts today indicate an early appearance of prototypes to demonstrate feasibility.

The very concept of self-healing is a technological breakthrough within itself. Reduction of this concept to practical application will be slow and laborious. Courageous and imaginative designs must be extended throughout the scale of product and system complexity from the molecular level of parts up to the level of compound machinery. Initial returns will probably be elementary and sometimes prosaic, but patience may eventually pay off in a significant and robust advancement of civilization.

Current development as opposed to mathematical manipulation in self-healing concepts reveal that the human race is still holding on while trying that first step. Very little has actually been done to reduce concepts to a practical level. The major indications are that self-healing systems are easy to contemplate, but rather difficult to achieve. True self-healing in an open concept is approaching self-reproduction and most of humanity is a little hesitant to pursue such a course in fear of the ultimate result.

CHAPTER 5

Contemporary Systems

There are many ATE systems in use and many more prototypes that can or may be used for checkout of military systems. None can be called "typical" since what is typical today will be obsolete tomorrow, and no two systems have the same characteristics. Test programming techniques are improving and equipment is becoming more readily tested as producers are becoming more aware of maintenance requirements. (For example, test points!) However, a "typical" diagnostic test program will consist of something like 100 tests with an average of 650-750 bits for each test. A total program will use about 75,000 bits of storage and 22,000 bits for messages. Messages identify tests and UUT, give instructions, and direct necessary repairs or subsequent action.[1] The following equipments are not all "typical" nor is this intended as an all inclusive listing of ATE. They are presented only as a brief indication of what is presently available in automatic test equipments.

ACRE - Automatic Checkout and Readiness Equipment

Designed and built by Lockheed Aircraft Corporation, Sunnyvale, California, under BuWeps contract NOrd 17017. Consists of a digital

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[1] A "bit" is a single digital computer storage location and means "binary digit." A bit may be a number, name, condition, or state. For instance, on and off are bits of information.

computer with associated remote test consoles and is used to automatically evaluate missile systems, sub-systems, and modules. A tape recorder is included to permanently preserve all test data. ACRE is used to evaluate missile systems, sub-systems, and modules.

APCHE - Automatic Programmed Checkout Equipment[2]

Produced by RCA, Burlington, Massachusetts. This is basically a card reader type and is presently being used to checkout the ATLAS ICBM. It also checks the operational readiness of the ATLAS launch control and ground support equipment. Tests and tolerances can be added or modified by appropriate card changes. The system is capable of self test.

BACE - Basic Automatic Checkout Equipment (AN/USA-11)

Produced by Autonetics Division of North American Aviation, Incorporated, Downey, California. Used for automatic and semi-automatic testing of the A3J-1 and W2F aircrafts on the flight line and in the maintenance shop. Through slight modification it can be used for testing similar systems. It is self-testing. Improved designs have been developed at U. S. Naval Avionics Facility, Indianapolis, Indiana.[3]

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[2]As indicated by B. T. Joyce and E. M. Stockton of Radio Corporation of America, Burlington, Massachusetts.

[3]Inspected by the author through courtesy of Commanding Officer, Avionics Facility, and Carl W. Schermerhorn, Engineering Dept., Avionics.

CAM - Checkout and Automatic Monitoring Equipment

Designed as a part of the Ballistic Missile Early Warning System. Provides system checkout and automatic monitoring of long range automatic radar systems. Automatically indicates equipment degradation and provides fault isolation. Provides aural and visual alarms upon fault detection and commences fault isolation upon insertion of punched cards. Results are automatically printed.

CPE - Central Programmer and Evaluator

Produced by Goodyear Aircraft Corporation of Akron, Ohio. A general purpose test equipment used to test the guidance and auxiliary power units of SUBROC. A punched-tape programmed system giving a confidence test with tolerance percentages.

DATICO - Digital Automatic Intelligence Checkout (SP-5)

Designed and produced by Nortronics Division, Northrop Corporation, Anaheim, California. A digital, automatic, tape programmed checkout family of systems. Has been associated with Polaris since 1958, and now has over 50 varied systems in use by the military services. Early models too noisy for submarine usage, but recent developments have made it compatible for submarine installation. Has self-testing features.

DATS - Dynamic Accuracy Test System

Produced by RCA of Camden, New Jersey. Used to support the MG-10 airborne weapons control system in the F-102. It is self-testing

and is used for dynamic closed-loop pre-flight checkouts of the F-102 weapons system.

DEE - Digital Evaluation Equipment

Produced by RCA of Camden, New Jersey. Is a family of test systems using field data code as program language and interchangeable building blocks for equipment components. Has self-test capabilities. DEE is an outgrowth of a study for an automatic test station to test a family of Army Ordnance missiles.

MART - Mobile Automatic Radiating Tester

Produced by Hughes Aircraft Company, Culver City, California. Purpose is to test automatically at remote stations the communications, navigation, landing, and identification sub-system in the F-106. Centrally located, it can receive transmissions from all aircraft to be tested through data link communications.

NARATE - Navy Radar Automatic Test Equipment

Developed by Nortronics Division of Northrop Corporation, Anaheim, California, under contract No. NObsr 81341. Part of the DATICO family, NARATE is a system integrated to checkout the AN/SPS-39A, AN/SPS-30, and AN/SPS-10 radars. Monitors performance and isolates faults. In-line readout provides a display of the measured value, evaluation results, type of measurement, test number, and provides a printout of such data. Is presently installed on the USS Columbus (CG-12), and

has self-test capabilities.

Summary

In addition to the above list the military services maintain documents on ATE being developed by Bendix, Emerson, General Electric, Minneapolis-Honeywell, Martin, Motorola, Sperry, and probably others. Although all of these may or may not eventually have military applications, most, if not all, will probably have some effect on various military systems in the future.

It is obvious that competition does exist in the electronics industry in research, development, and production of automatic test equipments. This may be expected to increase the reliability and effectiveness of any system. It may also be expected to increase the initial price of a system to the ultimate buyer, but long-range costs may be significantly reduced. The problem of standardization of parts may also be a vital one during initial phase-in periods. Whatever the cost in time, effort, and resources, if competition produces the wherewithal to successfully pursue the national economic and defense goals, the "dollar is well spent."

CHAPTER 6

Conclusions and Recommendations

Automatic testing is not a panacea for maintenance and reliability problems. ATE may be an even bigger problem for the operator than a test system with which he is familiar. Moreover, mistakes in ATE design have been commonplace and frequently expensive. A major cause for these mistakes is the headlong run toward automation when a more proper approach would have been a walk--if not a crawl. Another major cause is a propensity to overautomate. A computer that produces a solution in one microsecond is certainly not a million times as good as one that takes a whole second. In fact, it may not even be as good. However, it is safe to say that the cost of development and production is higher. This rationale includes the ATE systems. If the mission of the PE is limited, the requirement for repair and checkout is also limited. If the operator is limited in his mode of action, as for example, having only to decide whether to continue to the next phase or abort, the degree of checkout is limited to that necessary only for making this decision. Overautomating just presents unnecessary expense in both equipment and personnel. ATE in the right place at the right time and in the right configuration is a handy (sometimes necessary) tool. However, the decision to obtain ATE should be made only after detailed analysis of all relevant factors.

At present, there are four basic reasons for management decision to use ATE:

1. Automatic equipment by definition requires a minimum of operator participation and judgment in performing checkout.

There exists a general shortage of personnel adequately trained and skilled to perform manual testing on the modern complex electronic systems. ATE is expected to reduce the severity of maintenance problems due to such shortages. Initial experience in ATE operations revealed that rather than reduce personnel, as much as a fifty percent increase in quantity was required. Even more revealing was the necessity to have better quality (more highly skilled personnel) to maintain the ATE as well as the prime equipment. However, more recent design developments have indicated that a reduction in both skills and numbers of personnel in operational positions is a real probability. (Self-test features for instance.)

2. Automatic equipment can perform testing many times faster than manual methods.

In many instances, time is at a premium in terms of dollar costs, mission success, and degraded reliability. There is no question but what automated testing can significantly reduce the time needed to diagnose and locate malfunctions--as long as the test system itself functions properly. Self-testing features will increase ATE reliability as a function of the number of elements designed for self-test.

A self-healing system will further increase reliability and decrease MTTR for the ATE to the extent that its components are capable of such action. When seconds or fractions thereof can mean lives, such features assume more significance.

3. Automatic equipment performs all its operations precisely as commanded.

This feature fosters confidence in test results since continuity and standardization of test methods tend to eliminate most, if not all, external variables. By providing test results in a standard format, more efficient feedback is subsequently provided for new equipment or program design. The inflexibility of ATE is often mentioned as one of its greatest shortcomings, but it may also be one of its greatest assets. Just as humans sometimes cannot "see the trees for the forest," they often fail to pick up a specific malfunction in an array of faults. An ATE system points out each fault and continues to call attention to it until it is finally fixed.

4. There are instances in which it is impossible to perform test and checkout in any other way than automatically.

This constraint is generally due to equipment environment. Specific examples are unmanned space systems, environmental chambers, radiation hazard areas, and some silo mounted missiles. This remote checkout ability is particularly valuable in monitoring numerous systems simultaneously.

Recommendations

The recommendations which follow are presented as points deserving consideration by those who design, develop, produce, and purchase ATE. Even though the pursuit of more and better ATE is resulting in daily improvements, this philosophy is considered conservative enough to remain applicable to any envisioned advances.

1. Design ATE to function adequately under less than optimal support conditions.

Any test system must be capable of operating when its normal support is below standard. The acquisition of an expensive test system indicates that the prime equipment is of paramount importance, so an inoperative ATE may result in an inoperative weapons system. Therefore, the ATE must be capable of using battery power, and have provisions for alternate usage of certain parts, such as fuzes. This recommendation is somewhat in contradiction to designing for optimum performance, but it is reasonable to assume that conditions can and will arise when necessary support will be less than optimal.

2. Consider phase-in rather than concurrent procurement of ATE for specific prime equipments.

This course of action is inapplicable where ATE is absolutely necessary (e.g. environmental dictates), but in many instances it is a far more sensible approach. Automation is still a brand new art and is practiced skillfully by very few designers. Test equipment design

is completely dependent on the design of the prime equipment. By phasing-in or delaying ATE until the PE has been fabricated, laboratory tested, field tested, modified as required, and declared operationally ready, costly redesign of the ATE can be avoided. An interim system of manual tests and checkouts can be employed to ensure meeting operational dates. Manual testing will also discover many faults, and a better, more effective automated system can be erected around the knowledge of experience.

3. Retain some degree of flexibility in the design of the ATE.

No matter how long the automation process is delayed, some changes in PE are certain to occur after it becomes operational. Therefore, some provision should be made to allow changes in the system without the necessity to completely redesign. The "building block" concept is a major step in this direction. A design that requires only a program change rather than configuration modification is particularly desirable.

4. Provide an adequately trained maintenance staff to backup the ATE system.

Higher skilled technicians are better able to repair and work with the PE, thereby increasing its effectiveness. If a system is sufficiently important to warrant automatic testing, it is important enough to warrant the best available backup. In the limited confines of a ship, backup is generally always a manual system, and the better

the operator, the more reliable the whole system. Skilled operators are also more effective in improving test techniques and installing the inevitable field changes. Although manufacturers are fond of saying that an ape can run their product, animals are still forbidden aboard U. S. Navy ships.

5. Wherever possible, ensure that the ATE is used for end item testing in the factory.

ATE may not be available at the start of production, but when available it can contribute to better design in both ATE and PE if used extensively prior to fleet operations. If ATE and PE prove incompatible in the sterile environment of the laboratory, it is practically certain that they will be incompatible in the fleet. Concurrent use in production will also ensure that production and operational tolerances are identical.

6. Ensure that the ATE has self-test capabilities consistent with its reliability requirements.

Self-test equipment is usually capable of isolating malfunctions as soon as they occur. If all vital components are tied into a self-test configuration, then downtime due to fault isolation will be effectively zero. If faulty operation cannot be tolerated, or if certain tendencies of the PE must be immediately known (e.g. atomic reactors going critical), then the self-test features must be as complete and reliable as the ATE itself. Regardless of the severity

of catastrophe considerations, self-test features should be present in all ATE to some degree.

Self-testing systems should also be diagnostic to the extent that they indicate the general nature of any malfunction. It is not always enough to indicate that a system is GO. Some indication of the remaining useful life of certain specific components, while useful in any case, may be of critical significance in scarce or long-lead-time components. Systems are available that will isolate a fault and print out its location, stock number, and storage area. It should be possible to have a complete printout of certain selected components indicating significant measurements and predicted life of such components. The next obvious step is to have the machine print out supply order forms for components when they reach a certain point in wear but physical restraints must be exercised somewhere!

Self-healing systems are in essence but an extension of self-testing concepts. Man is well on his way to realization of machines that can repair themselves. There are hurdles aplenty in the way, but it has been less than ten years since effective self-test features appeared. Now that machines can indicate specific "ills," the next step is "physcian, heal thyself!" To many scientists and engineers, the "ultimate" in ATE is a machine that can evaluate the inherent, intrinsic qualities of a system and not only tell if it is functional, but do something about it if it is not.

CHAPTER 7

Summary

Many military systems depend upon automatic test equipment for their operational effectiveness. The peacetime role of ATE is readiness appraisal and maintenance testing, while its role during hostilities is expanded to include operational readiness and/or prelaunch checkout. Key factors in designing an efficient and effective system are the roles assigned to men and machines and the degree of teamwork required between the two. Although a wide variety of design principles can and have been developed, each test system, because of its particular tasks and environment, requires a unique tailoring of man-machine trade-offs. Success in this effort is an art that requires extensive experience as well as talent and perception.

The necessity for ATE is based on a prime system which by virtue of complexity, mission availability, and reliability requires a low mean time to repair. These factors also require that the ATE have a low mean time to repair. A low MTTR depends on some form of self-test configuration which also results in increased weapon reliability, increased confidence in both PE and ATE systems, and decreased necessity for specialized technician training. The costs in resources and reduced payloads of incorporating self-test features are considerable, but the potential cost of not having them is frequently

far greater.

The next step in the development of more reliable systems is the self-healing concept. A system that automatically locates and diagnoses its own faults and then automatically repairs itself is a distinct possibility. There are many closed type self-healing systems in use today, and open type systems may reasonably be expected in the near future. The very concept of self-healing is approaching the threshold of self-reproduction, and men can be expected to be somewhat hesitant in the pursuit of such an ultimate result.

Most electronic firms are producing or developing ATE in one form or another. An effective evaluation of which is best depends on what it is expected to do. Certain basic features are common to all systems, but there are enough differences to require careful and exhaustive selection. A particularly sophisticated system may even require concurrent or follow-on construction of ATE to conform with the PE and its modifications. The competitive nature of the electronics industry may be depended upon to keep potential purchasers informed of all developments in ATE. Effective selection then depends upon an informed procurement organization. This paper is intended to provide part of that necessary information.

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